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# MODEL FOR EVALUATION OF PLASTIC PROPERTY BASED ON HARDNESS OF HEAT AFFECTED ZONE (HAZ), APPLIED LOAD AND FINAL LENGTH OF MILD STEEL WELDMENT

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## ABSTRACT

This paper presents a systematic approach to develop the mathematical model for predicting plastic property (ductility) of mild steel weldment employing shielded metal – arc welding process. The derived model; $\alpha = H(\frac{\gamma}{\O})^{1.4925}$ shows that the relative elongation is a direct function of the hardness of the HAZ, load applied and final length. Correlation of the relative elongation with the independent variables suggest that the final length had strong influence on the predicted parameter (relative elongation) most compared to other variables(hardness of HAZ and applied load). Model predicted values were compared with the corresponding experimental data, the closeness in the values is indicative of the proximate agreement between both. The maximum deviation of model predicted data from the corresponding experimental values was less than 14.37% which is quite within the acceptable deviation range of experimental results and so the model is considered reliable. The developed model can be used effectively at 85.63% confidence level.

KEYWORDS: Model; evaluation, relative elongation, mild steel weldment.

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## INTRODUCTION

Fundamental mechanical properties of metals are related to the amount of deformation which metals can withstand under different circumstances of force application (Higgins, 1993). Ductility refers to the capacity of a substance to undergo deformation under tension without rupture, as in wire or tube drawing operations. Since these fundamental mechanical properties of ductility, malleability, and toughness cannot be expressed in simple quantitative terms, it has become necessary to introduce certain mechanical tests which are related to these properties and which will allow for comparative numerical interpretation.

Moreover, the engineer is more concerned with the forces which cause deformation in metals rather than with the deformation itself. Such precise measurements of force deformation values make it possible to draw up sets of specifications upon which the mechanical engineers can base his design (Higgins, 1993).

The general behaviour of materials under load can be classified as ductile or brittle depending upon whether or not the material exhibits the ability to undergo plastic deformation. Adequate ductility is an important engineering consideration, because it allows the material to redistribute localized stresses (Dieter, 1988). The basic data on the mechanical property of ductile metal are obtained from a tension test, in which a suitably designed specimen is subjected to increasing axial load, until it fractures. The load and elongation are measured at frequent intervals during the test and are expressed as average stress and strain. The determination of this property is quite tedious, not at all routine, and dependent on the sensitivity of the strain- measurement instrument. In view of this, several authors have designed models that have been used effectively in predicting the mechanical behaviour of weldment in service using different welding parameters and processes. Mathematical modeling is very important because it allows some rather expensive and repetitive experimentation to be avoided (Turner and Perre, 1997). Nwoye (2011) formulated model for assessing and predicting the hardness of HAZ of aluminium weldment cooled in groundnut oil in relation to similarly cooled mild steel and cast iron weldments. Palanivel et al, (2011) developed a mathematical model to predict the mechanical properties of friction stir welded AA6351 aluminium alloy. Kolahan and Heidari (2009) used experimental data to relate important process parameters process output characteristics, through developing empirical regression models for various target parameters. Computational analysis of the models results shows that the experimental results and the model predicted results are in proximate agreement, hence depicting the usefulness of models in engineering. The present work is aimed at deriving a mathematical model that could be used to evaluate plastic property (ductility) in a cost effective way based on known values of hardness HAZ , applied load, and final length of mild steel weldment.

## MATERIALS AND METHODS

The following materials and equipment were used for the research work: mild steel plates, SMAW Unit (AC), welding transformer (STICK and TIG Mode with inbuilt-rectifier), 3.2 × 350mm electrode (rutile), electrode drying oven, stop watch, digital multimeter, metallurgical cut-off wheel and tensometer. The tensile properties of the base material used in this research are presented in Table 1. The full details experimental procedures are presented in (Adzor, 2012).

Model Formulation

Experimental data obtained from research work (Adzor, 2012) carried out at the Department of Metallurgical and Materials Engineering, Nnamdi Azikiwe University, Awka were used for this work. Computational analysis of experimental data (Adzor, 2012) shown in Table 2, which gave rise to Table 3, indicates that,

$$\frac{r}{\O} \approx \left(\frac{\alpha}{\mathcal{H}}\right)^{m} \quad \text{.................................................(1)}$$

Multiplying the indices of both sides of equation (1) by $1/m$

$$\left(\frac{r}{\O}\right)^{1/m} = \frac{\alpha}{\mathcal{H}} \quad \text{.................................................(2)}$$

Where m = 0.67

Introducing the value of m into equation (2) reduces it to ;

$$\left(\frac{r}{\O}\right)^{1/0.67} = \frac{\alpha}{\mathcal{H}} \quad \text{..............................................(3)}$$

$$\left(\frac{r}{\O}\right)^{1.4925} = \frac{\alpha}{\mathcal{H}} \quad \text{.................................................(4)}$$

$$\alpha = \mathcal{H}\left(\frac{r}{\O}\right)^{1.4925} \quad \text{.............................................(5)}$$

where;
ɤ = Load (KN)
Ø = Final length (m)
$\alpha$ = Elongation (%)
$\mathcal{H}$ = Hardness of HAZ
m = Constant (0.67); Equalizing constant [Determined using C-NIKBRAN (Nwoye, 2008)]

### Analysis of derived model

The derived model indicates that the relative elongation is a function of the hardness of the heat affected zone(HAZ), load applied and final length of the welded metal. Based on the foregoing, the relative elongation of the welded steel can be predicted by simply substituting known values of the applied load, hardness of the HAZ and the final length of the welded steel. Furthermore, with specification of a material, of known values of desirable relative elongation, hardness of the HAZ and final length of the welded metal, the model could be used to predict the load which the weldment can sustained prior to failure.

The standard error (STEYX) in predicting the value of relative elongation for each value of the final length in the derived model are;
Ex = 0.0024
MoD = 0.6017
LSM = 0.00002

Correlation between relative elongation and final length are;
Ex = 0.9999
MoD = 0.8282
LSM = 1.0000

Correlation between relative elongation and HAZ are;
Ex = 0.8147
MoD = 0.6834
LSM = 0.8152

Correlation between relative elongation and load applied are;
Ex = 0.1711
MoD = 0.4836
LSM = 0.1710

The values of the correlation between the relative elongation and final length, relative elongation and hardness of HAZ, and relative elongation with load applied were obtained using excel 2003 version software. The correlation (0.8282) and (0.9999) between the relative elongation and final length of the derived model and experiment are quite close and approximately equal to 1, when compared to the correlation (0.6834) and (0.8147) between the relative elongation and hardness of the HAZ and the correlation (0.4836) and (0.1711) between the relative elongation and load applied of the derived model and experiment respectively, it can be concluded that the final length of the welded steel, played the major role in arriving at the extent to which the welded material was stretched ( elongation). This implies that the final length affected the value of the relative elongation most compared with other variables( applied load and hardness of HAZ).

Boundary Condions;
Final length = 250 - 259 mm ( 0.25- 0.259m)
Load = 80,878 - 89,540N (80.878 - 89.54 KN)
Elongation = 8.702 - 12.612%

Hardness of HAZ = 52- 62.5 $HR_B$

Standard errors were evaluated for independent variables affecting the predicted parameter. In the derived model, the final length was used in determining the standard errors because it affected the relative elongation most.The three variables (load, hardness of HAZ and final length) make up the model because when load is added, change in length will occured and then elongation can be calculated.

Symbols;
Ex - Results obtained from experiment
MoD - Result predicted by derived model
LSM - Results predicted using least square method

Model Validation
Deviational analysis
The derived model was validated using deviational and statistical analysis. Deviational analysis involves direct analysis and comparison of model predicted values with those obtained from experiment for equality or near equality. Analysis and comparison between these values revealed deviation of model predicted values from those of the experiment as shown in Table 3. The maximum deviation of the model predicted values of relative elongation from experimental results evaluated is 14.37% was found to be very low and quite within the acceptable range for experimental results. This gives a confidence level of 85.63%. Hence, the model is considered reliable. The closeness in the model predicted results with those of the experimental is an indication of the proximate agreement between both. The deviations of the model predicted values of relative elongation from the corresponding experimental values is believed to be due to the fact that the surface properties of the welded steel and the physiochemical interactions between the weld zones and the surrounding which played vital roles (during the welding operations) were not considered during the model formulation. It is expected that the introduction of the correction factor to the model predicted values of relative elongation gives exactly the corresponding experimental values.

Deviation ($D_v$) of model predicted values from the experimental values is given by;

$$D_v = \frac{(M_oD - Ex)}{Ex} \times 100\% \qquad (6)$$

Where,
$M_oD$ = Model predicted values
ExD = Experimental results

Correlation factor (Cf) is the negative of the deviation i.e

$$Cf = - D_V \qquad (7)$$

Introduction of the corresponding values of Cf from equation (7) as shown in Table 3 into the model gives exactly the corresponding experimental values. Results of deviational analysis as shown in Table 3 shows that the derived model is valid since the model deviations from experimental values are generally quite within the acceptable range for experimental results.

Statistical analysis
Statistical analysis involves the evaluation of the correlations between the process variables. In the derived model, the correlation between relative elongation and the final length are 0.9999 and 0.8282 as obtained from experiment and derived model respectively. Similarly, the correlation between relative elongation and the hardness of HAZ are 0.8147 and 0.6834 as obtained from experiment and derived model respectively. While the correlation between

relative elongation and load applied are 0.1711 and 0.4836 as obtained from experiment and derived model respectively. Based on the foregoing, it is strongly believed that the proximity of the correlations of experimental and model predicted results are indicative of the model validity.

## RESULTS AND DISCUSSIONS

The derived model is equation (5). Computational analysis of experimental results presented in Table 2 gave rise to Table 3. Table 3 shows the relative elongation obtained from experiment, derived model and least square method. It is clearly evident that the values of tensile strength and relative elongation obtained from experiment, derived model and least square method are in close approximations. Thus, the model equation, giving relative elongation as a function of the applied load, final length of the welded metal and hardness of the HAZ is demonstrably accurate and simple enough to be of engineering usefulness in predicting the values of relative elongation in the steel weldment. The dashed lines seen in Table 3, is an indication that not all the values of the parameters in the experiment fit into the model equation. Therefore, only values that showed some degree of relationship between the variables (dependent and independent) that were used in the model equations. The closeness in the model predicted values of the relative elongation with those of the corresponding experimental values is an indication of the proximate agreement between the experimental and model predicted results. The maximum and least deviations of the model predicted values of relative elongation from the corresponding experimental results are 14.37% and -1.01%, which is quite within the acceptable deviations range of experimental results.

Figure 1 shows the variation of relative elongation with hardness of the HAZ of welded metals. It is observed that as the relative elongation decreases, the hardness of the HAZ also decrease, as it began to increase, the hardness of the HAZ also increase and it remain constant with further decrease in the value of the relative elongation. The observed trend could be attributed to the microstructural grain size in the HAZ of the welded metals.

Figure 2 shows the variation of the relative elongation and load applied of welded metals. It was evident that as the relative elongation decreased the load applied also decrease and as the load applied began to increase the relative elongation also increased. The observed behaviour could be attributed to the characteristics features of the microstructure formed in the steel weldment.

Figure 3 shows the variation of the relative elongation with final length of welded metals. It is observed that at first, the relative elongation decreases as the value of the final length decreases and thereafter began to increase with further decreased in the final length. The amount of extension expressed as percentage of the original gauge length is affected by the microstructural grain size, hence, the observed trend.

## CONCLUSION

A comparison of results obtained from the study with those estimated using the formulated model are in proximate agreement, hence, the model could serve as a useful tool in engineering for predicting the amount of plastic deformation a mild steel weldment would undergo in service before fracture. It was noticed that the final length of the welded steel, played the major role in arriving at the extent to which the welded material was stretched ( elongation).This implies that the final length affected the value of the relative elongation most compared to other variables (applied load and hardness of HAZ).

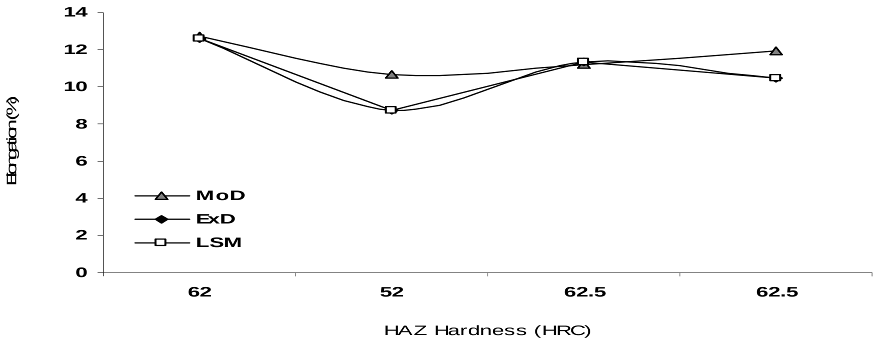

Figure 1 : Variation of relative elongation with hardness of the HAZ of welded metals.

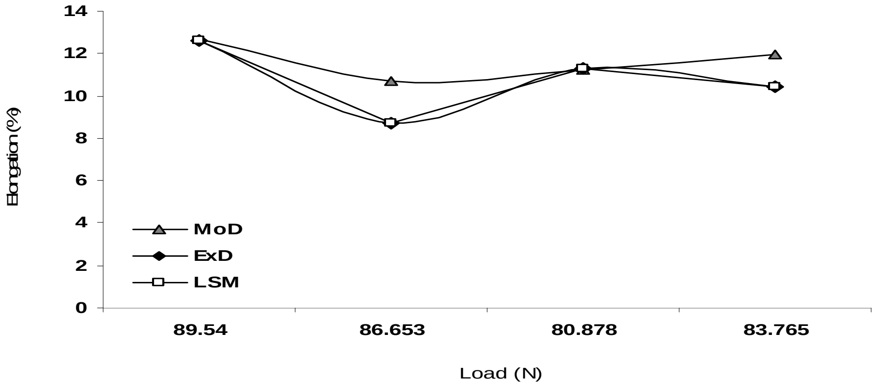

Figure 2: Variation of relative elongation with load applied of welded metals.

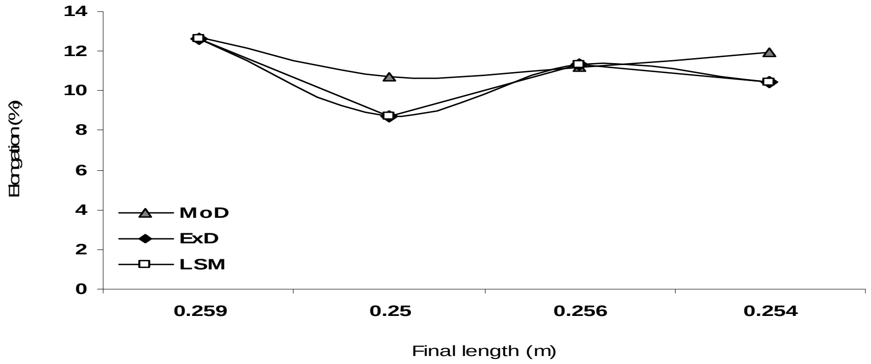

Figure 3: Variation of relative elongation with final length of welded metals.

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Table 1: Tensile properties of the as - received mild steel plate.

| Base material | Tensile strength (N/mm$^2$) | Relative elongation (%) |
|---|---|---|
| Mild steel (0.158%C) | 411,073 | 17.4 |

Table 2: Hardness and gauge length of welded steel plates at different welding conditions.

| Sample No. | Welding conditions | Load applied (N) | Gauge length (mm) | | Hardness of HAZ (HRB) |
|---|---|---|---|---|---|
| | | | L$_o$ | L$_f$ | |
| TP1 | 120A(AC) | 89,540 | 230 | 270 | 62 |
| TP2 | 125A(AC) | 86,653 | | | 52 |
| TP3 | 120A(DC-) | 80,878 | 230 | 250 | 62.5 |
| TP4 | 125A(DC-) | 83,765 | 230 | 256 | 59 |
| TP5 | 120A(DC+) | 86,653 | 230 | 264 | 50 |
| TP6 | 125A(DC+) | 83,765 | 230 | 265 | 62.5 |
| | | | 230 | 254 | |

Table 3: Relative elongation as obtained from experiment, derived model and least square method.

| Relative elongation (%) | | | Dv | Cf |
|---|---|---|---|---|
| ExD | MoD | LSM | | |
| 12.612 | 12.703 | 12.612 | 0.72 | -0.72 |
| 8.702 | 10.696 | 8.701 | 22.9 | -22.9 |
| 11.309 | 11.195 | 11.308 | -1.01 | 1.01 |
| - | - | - | - | - |
| - | - | - | - | - |
| 10.436 | 11.935 | 10.439 | 14.37 | -14.37 |

LIST OF SYMBOLS
ExD = Results obtained from experiment
MoD = Result predicted by derived model
LSM = Results predicted using least square method
Dv = Deviation (%)
Cf = correction factor (%)
ɤ = Load (N)
Ø = Final length (m)
α = Elongation (%)
$\mathcal{H}$ = Hardness of HAZ
M = Constant(0.67); Equalizing constant[Determined using C-NIKBRAN( Nwoye, 2008)]